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The Impact of Gamification on Cybersecurity Learning: Multi-Study Analysis

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Abstract:

Gamification is a popular learning technique that can be employed to enhance learner's interest in their careers by presenting them with realistic scenarios and practical problem-solving experiences. However, the effectiveness of this method has not been fully investigated in the context of cybersecurity learning. This study aims to systematically assess the impact of gamification on cybersecurity learning. Through a multi-study approach, we conducted a four-semester-long experiment to integrate gamification into an undergraduate cybersecurity course, comparing learning outcomes in gamified and traditional labs as well as analyzing learners' perceptions, motivation, and career interests in gamified cybersecurity lab experiences. In addition, qualitative interviews reveal how students interact with these labs and identify game elements that significantly impact their learning experience. Our findings provide theoretical contributions by expanding the literature on gamification's role in cybersecurity learning and practical strategies for seamlessly incorporating gamification into cybersecurity learning experience.

Keywords: Gamification, Cybersecurity Learning, PLS-SEM, Mixed-method Design.

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1 Introduction

With digital transformation and the trend toward cloud migration, cybersecurity has become a critical issue for organizations. It requires the continuous refinement and modernization of cybersecurity education to strengthen the cybersecurity workforce. The 2023 (ISC)² Cybersecurity Workforce Study reveals that cybersecurity professionals and hiring managers prioritize on-the-job experience over traditional education, underscoring the significance of practical training in conventional cybersecurity curricula. This need for innovative training approaches is further highlighted in the 2024 (ISC)² report, which shows that the cybersecurity workforce gap has expanded to 4.76 million, a 19.1% increase from 2023. Both the 2023 and 2024 (ISC)² findings emphasize that empowering the next generation of cybersecurity professionals through practical, engaging training is a critical need, particularly as we move into an AI-driven world where cyber threats are more complex than ever before. Hence, many cybersecurity curricula adopt hands-on training to provide real-world situational training to the learners. Hands-on training in cybersecurity demands high levels of engagement because it involves active participation and direct interaction with real-world scenarios. This type of learning requires students to apply theoretical knowledge practically, which can be challenging to sustain without sufficient motivation and interest. Gamification can play a crucial role in hands-on training by infusing educational content with game-like elements such as scoring systems, challenges, and achievements. It involves the application of game design elements, principles, and mechanics in non-game contexts to enhance user engagement and motivation, which has shown promise in boosting learner motivation, increasing engagement, and improving learning outcomes (Krath et al., 2021). Many studies provide evidence of its transformative potential across various fields, enhancing both knowledge retention and skill development (Kiryakova et al., 2014; Landers & Callan, 2011; Hamari et al., 2014).

Studying the impact of gamification in cybersecurity education is critical because of the distinct challenges that make this field, unlike other areas of study. Cybersecurity demands not only technical proficiency but also critical thinking and quick adaptation to an ever-changing threat landscape. Traditional educational methods often struggle to fully engage students in mastering complex skills such as network defense, threat detection, and vulnerability assessment (Rice & Sambasivam, 2022, Towhidi & Pridmore, 2023). Unlike other disciplines of higher education, where theoretical knowledge may suffice, cybersecurity requires hands-on, real-world problem-solving abilities. Gamification has the potential to address these unique needs by creating interactive, immersive learning experiences that build both technical expertise and the critical mindset necessary for cybersecurity professionals. This makes it especially important to study how gamification impacts learning outcomes specifically in cybersecurity education, where the stakes and skills required significantly differ from those in other disciplines. Although gamification has been widely embraced in extracurricular activities, its use in classroom settings remains underexplored. Investigating how gamification impacts learning in structured classroom environments is crucial, as it may yield different effects compared to informal educational contexts. Additionally, with the ongoing shortage of skilled cybersecurity professionals, effective training strategies are more important than ever (Towhidi & Pridmore, 2023). To prepare students for successful careers in cybersecurity, it is essential to foster genuine interest and provide realistic scenarios that build practical problem-solving skills. Gamification offers a promising approach to achieve this by creating engaging and immersive learning experiences. This study aims to explore these dynamics and fill gaps in the literature regarding the role of gamification in classroom settings, particularly in specialized technical education fields like cybersecurity.

While motivation is crucial in both extracurricular and classroom settings, their focus differs significantly. Extracurricular activities often emphasize student engagement and retention, whereas classroom education prioritizes learning outcomes. In the context of cybersecurity education, which emphasizes learning through hands-on exercises, it is especially important for students to connect their activities directly to the learning objectives. Although gamification can make learning more engaging by incorporating game-like elements, research indicates that its playfulness does not necessarily translate to improved learning outcomes (Rumangkit & Larasati, 2023). Additionally, the competitive nature of gamification may unintentionally create pressures that could discourage students who struggle with technical content. Therefore, understanding how gamification influences both motivation and learning in a demanding field like cybersecurity is essential for identifying effective ways to integrate it and support the learning of all students. Furthermore, the role of gamification in fostering students' career interests has not been fully investigated in the context of cybersecurity education.

Given the current emphasis on cybersecurity education and the growing awareness of the potential advantages and concerns of incorporating gamification into cybersecurity education, we have formulated the following as our first research question:

RQ1: Do gamified cybersecurity labs help learners achieve better learning outcomes in various cybersecurity topics compared to traditional learning methods in classroom settings?

In order to address this research question, we have created a series of cybersecurity lab exercises for an undergraduate network security course. After an extensive development process, we implemented gamified labs to enhance student learning. We conducted the first empirical study to compare the learning outcomes of students engaged in gamified labs versus those in non-gamified labs to assess the effects of gamification on students' learning outcomes. After obtaining positive results, we proceeded to the next research question to explore the factors that impact students' learning outcomes and career interests:

RQ2: What is the learning process through the gamified cybersecurity labs, especially focused on their intrinsic/extrinsic motivation, learning outcomes, and career interests?

To address this research question, we conducted a second study in which we designed survey questionnaires to measure students' perceptions of the gamified labs after they completed them. In this study, we used a partial least squares structured equation modeling (PLS-SEM) method to analyze the survey results and test hypotheses related to students' motivation, challenge, competitiveness, learning outcomes, and career interests. With a comprehensive understanding of the factors that impact students' learning outcomes and career interests, we further investigated their learning experience and feedback by posing the final research question:

RQ3: How do students perceive their learning experiences in gamified cybersecurity labs, and what specific feedback do they provide regarding the effectiveness of gamification in enhancing their engagement, understanding, and career interests?

We conducted semi-structured interviews with students after they completed gamified cybersecurity labs. The findings helped us validate the findings from Studies 1 and 2 and also identified additional areas that can be explored in future studies.

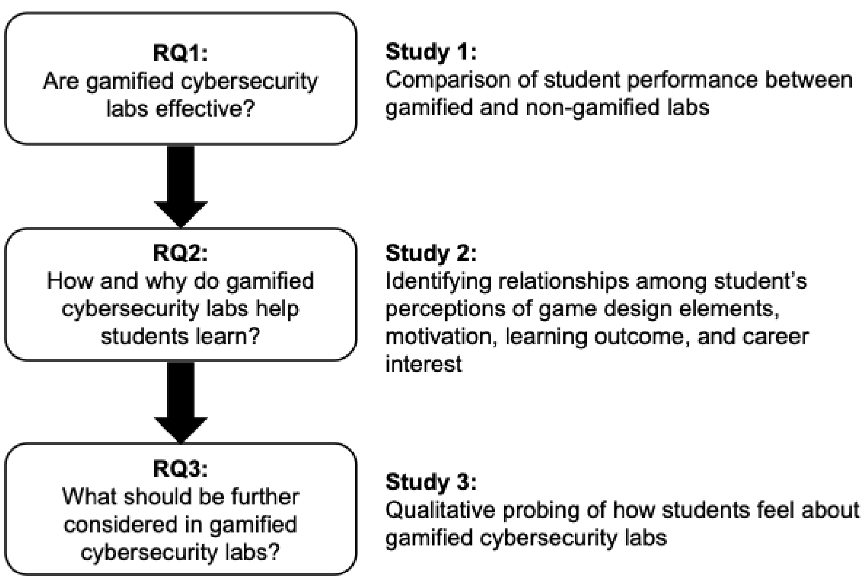


Figure 1. Study Agenda

Figure 1 illustrates the structure of our multi-study approach, including the research questions we pose and the focus of each study. Through a multi-study approach, we conducted a comprehensive four-semester-long experiment to integrate gamification into an undergraduate cybersecurity course. The paper makes significant contributions to the theory of game-based learning and cybersecurity education by expanding the literature on gamification's role in cybersecurity education while offering practical strategies for seamlessly integrating gamified approaches into cybersecurity labs. It provides a comprehensive assessment of the impact of gamification on learning outcomes, revealing how game-like elements can foster deeper engagement and knowledge retention. Furthermore, the study explores the nuances of competitiveness and game design and uncovers their impact on the student's motivation, learning outcomes, and career interests. By analyzing these intricate elements, the research equips cybersecurity educators with evidence-based strategies for effectively weaving gamification into practical cybersecurity lab scenarios. This holistic study empowers educators to ensure that the learning experience is not only engaging but also aligned with the core objectives of the curriculum, ultimately bridging the gap between theoretical knowledge and practical skills in the field.

2 Study Background

2.1 Gamification Literature

Gamification involves incorporating game elements into non-entertaining contexts (Deterding et al., 2011). Common game elements include competitions, reward points, leaderboards, badges, etc. Donovan and Lead (2012) suggest that gamification is a suitable approach for teaching various skills to younger generations who are accustomed to gaming and prefer to have fun while learning. Van Eck (2006) also argued that digital game-based learning is effective for several reasons, including situated cognition, assimilation/accommodation, and engagement. With the rise of digital technology, gamification has captured the attention of researchers interested in improving education and training processes on various topics. Table 1 summarizes important research on the use of games in the field of education and training as follows:

1) Concepts of gamified learning: Van Eck (2006) is one of the first works that discussed the effectiveness of gamified learning, followed by other works defining the concept of gamification (Deterding et al., 2011), reviewing key concepts and examples of gamification (Glover, 2013), and developing a taxonomy of gamification concepts (Schmidt-Kraepelin et al., 2018).
2) Design principles of gamified learning: Works such as de Feritas and Oliver (2006), Zaman et al. (2012), and Park et al. (2019) investigate issues regarding designing gamified learning processes using design science approaches. There are also works using conceptual designing, such as Liu et al. (2017), which primarily provide design principles for effective gamification.
3) Evaluation of gamified learning: Various works have investigated the effectiveness of gamification through empirical study. They focus on various elements of gamified learning, such as badges, leaderboards, and feedback that could affect learners' perceptions, performances, and behaviors. The context of the studies also varies from traditional classroom settings to online learning and massive open online courses. The findings of the empirical studies are mixed, with some showing clear relationships and others not. Many conclude that the success of gamified learning depends on factors such as context, instructor's capability, and student characteristics.
4) Literature review of gamified learning: Some studies aim to synthesize the findings of previous work on gamification by reviewing the literature. Most of them also find that successful gamification is dependent on various factors, emphasizing the need for further studies in the field.

More details of the research, including research context, theoretical framework, research methods, and main findings are available in Appendix A.

Table 1. Gamification Literature

Research Theme	Literature	Research Theme	Literature
Concepts of gamified learning	Van Eck (2006) Deterding et al. (2011) Glover (2013) Schmidt-Kraepelin et al. (2018)	Evaluation of gamified learning	Santhanam et al. (2016) Leung et al. (2023) Cronan et al. (2012) Dominguez et al. (2013) Cheng et al. (2009) Hanus and Fox (2015) Burguillo (2010) Ding et al. (2017) Kyewski and Kramer (2018)
Design principles gamified learning	de Feritas and Oliver (2006) Zaman et al. (2012) Park et al. (2019) Liu et al., (2017)		

Literature review of gamified learning	Susi et al. (2007) Young et al. (2012) Hamari et al. (2014) Antonaci et al. (2019) Sailer and Homner (2019) Majuri et al. (2018) Koivisto and Hamari (2019) Dicheva et al. (2015)		Cheong et al. (2014) Hakulinen and Auvinen (2014) Mekler et al. (2017) Landers et al. (2017) van Roy and Zaman (2018) Zhou et al. (2020) de-Marcos et al. (2016) Krause et al. (2015) Tenório et al. (2016) Tsay et al. (2018) Haug et al. (2014)

2.2 Gamification in Cybersecurity Education

Gamification has been widely used in cybersecurity training and extracurricular activities, such as Capture-The-Flag (CTF), workshops, and summer camps. Coenraad et al. (2020) noted that as of fall 2018, there were 181 cybersecurity games on the market, providing a detailed overview of these games based on characteristics like platform, developer, playtime, target audience, visual realism, camera view, anthropomorphism, narrative, gameplay actions, and how cybersecurity content is presented. It has proven effective in engaging participants. Adams and Makramalla (2015) explored various gamified training approaches in cybersecurity, examining aspects such as awareness, defensive and offensive strategies, as well as attacker-centricity. Beuran et al. (2016) suggested a framework that considers the skills, environment, and cost requirements for cybersecurity training activities, aligning them with suitable training approaches.

Studies have also been conducted to integrate gamification into classrooms. Gamification in cybersecurity is likely to increase student attention and motivation during the learning process (Demmese et al., 2020) and also improve the efficiency and effectiveness of both educational and workforce training programs (Wolfenden, 2019). Karagiannis and Magkos (2021) reported that students found digital game-based learning in cybersecurity to be an adequate educational method. Assessing the potential concerns of instructors when deciding whether to incorporate gamification, teaching suggestions were provided for implementing gamification in the classroom (Kim et al., 2023).

3 Study 1: Comparison of Learning Outcomes between Non-Gamified Labs and Gamified Labs

3.1 Study Design

The first study aims to assess the impact of gamification on learning outcomes within a network security lab exercise setting. We developed four gamified labs and four non-gamified labs for students enrolled in an undergraduate network security course at a medium-sized university in the southeastern United States. All the courses provided nearly identical materials and required students to play four gamified lab exercises related to course topics. Each student played the gamified lab exercises individually. Table 2 presents the details of these labs. The study was structured to compare the effectiveness of gamified labs against non-gamified labs across four consecutive semesters. The gamification elements implemented in this study include story narratives, reward points, instant feedback, and leaderboards, as demonstrated in Figure 2. During each semester, a sequence of four gamified labs was delivered, followed by four non-gamified labs. Each lab lasted about one week. Therefore, every student was able to participate in the same number of the gamified and non-gamified labs. This design was motivated by practical considerations, including differences in instructors, small class sizes each semester, and concerns about grading fairness. To ensure consistency in difficulty, we took several steps across the labs: (1) When designing these labs, we carefully reviewed the content using subject matter expertise to ensure that each lab presented similar levels of difficulty. (2) We designed tasks in each lab to be similar in the nature of complexity. For example, tasks such as running Linux commands in virtual machines, reading articles to answer questions, and completing review questions were consistently implemented across both gamified and non-gamified labs. This approach was intended to maintain equivalent levels of challenge. (3) We continuously collected student feedback and calibrated the difficulty levels of the labs based on this feedback.

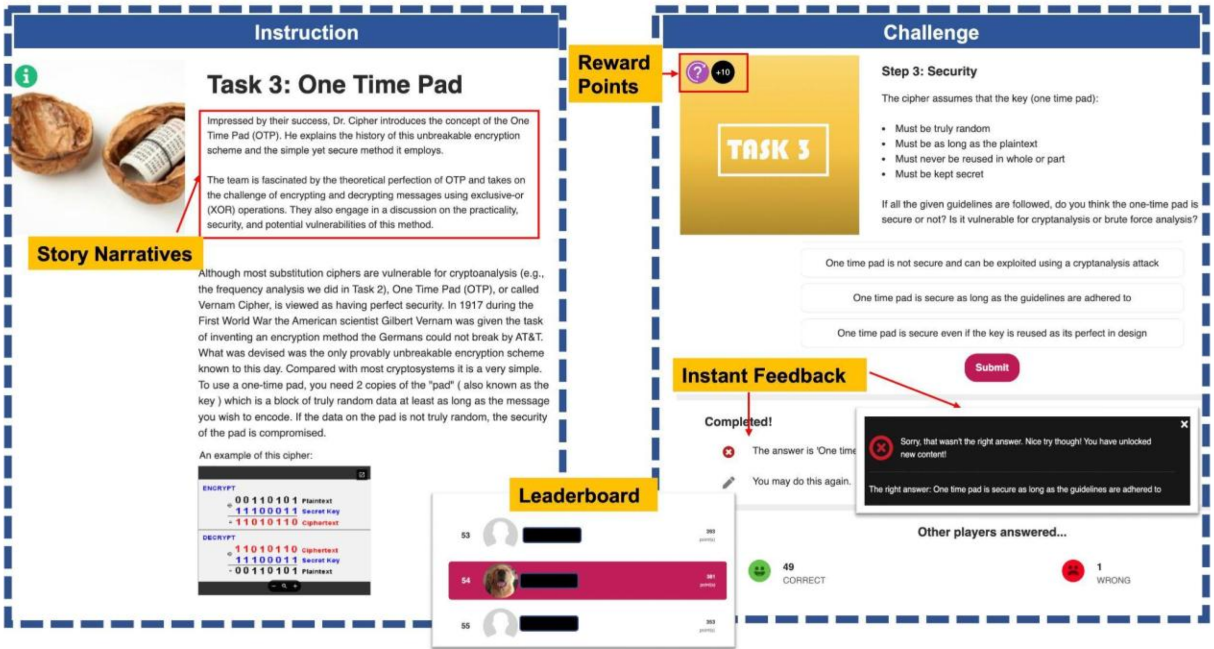


Figure 2. Demonstration of Gamification Elements, Including Story Narratives, Reward Points, Instant Feedback, and Leaderboard.

Following the completion of each lab, students were required to take a quiz one week later, which included multiple-choice questions designed to evaluate their understanding of the lab content. Additionally, we designed questions in the final exam that directly relate to the lab topics, allowing us to measure the learning outcomes at the end of the semester. There were 125 students who consented to participate in our study. The distribution of participants and the instructors responsible for delivering the labs in each semester are detailed in Table 3.

Table 2. The Descriptions of Gamified Labs and Non-Gamified Labs

Labs	Gamified (Yes/No)	Delivery Week	Tasks
Lab 1	Yes	1	Task 1: Frequency analysis against substitution cipher Task 2: Understanding one time pad cipher Task 3: Using openssl to encrypt multiple symmetric ciphers Task 4: Comparing different block encryption modes (ECB vs CBC) Task 5: Using initialization vector in encryption
Lab 2	Yes	3	Task 1: Learning RSA using an online tool Task 2: Cracking a weak RSA Task 3: Public-key encryption using Openssl Task 4: Digital signature Task 5: Man-in-the-middle scenario and exploring X.509 Certificate
Lab 3	Yes	5	Task 1: Using Wireshark to filter traffic and drive-by-download event Task 2: Exporting objects using Wireshark Task 3: Analyzing DNS traffic Task 4: Analyzing FTP traffic Task 5: Analyzing port scanning traffic
Lab 4	Yes	13	Task 1: Understanding WEP and identifying beacon packet Task 2: Cracking a weak wireless network Task 3: Configuring a secure wireless network Task 4: Search geo-location using MAC addresses of the access points Task 5: Practicing Aircrack-ng

Lab 5	No	7	Task 1: Analyzing HTTP headers Task 2: Using wireshark to decrypt TLS packers Task 3: Email authentication: DKIM, SPF, DMARC Task 4: Understanding email header Task 5: Detecting phishing emails
Lab 6	No	8	Task 1: Network setup Task 2: Normal user activities in the web server Task 3: Launching a heartbleed attack Task 4: Analyzing the root cause of heartbleed attack using a simulated program Task 5: Fixing the heartbleed vulnerability
Lab 7	No	9	Task 1: Network setup Task 2: Monitoring network traffic and server's TCP connection status Task 3: Launching TCP SYN flooding attack Task 4: Launching TCP RST attack to disrupt the telnet connection between the client and server Task 5: Launching TCP RST attack to disrupt the client's connection to Youtube.
Lab 8	No	10	Task 1: Network setup Task 2: Understanding ARP Man-In-The-Middle scenario Task 3: Using sslstrip Task 4: Launching ARP Man-In-The-Middleattack using Ettercap. Task 5: How to detect ARP Man-In-The-Middle attack

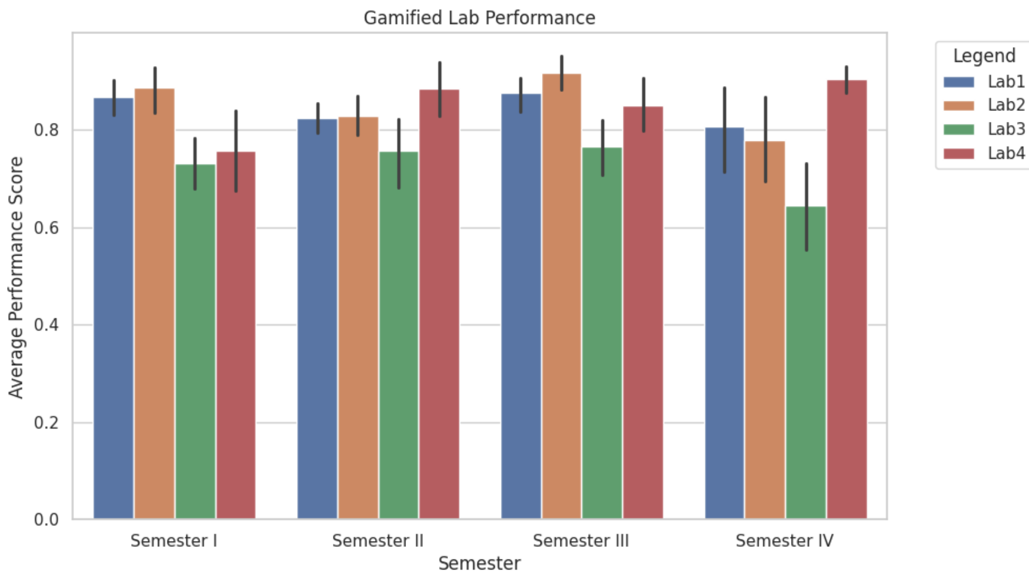
Table 3. The Participants' Background in Study 1

Semester	# of Participants	Junior	Senior	Female*	Male*	Instructor
I	31	10 (32%)	21 (68%)	12 (39%)	19 (61%)	A
II	37	15 (41%)	22 (59%)	11 (30%)	24 (65%)	B
III	41	13 (32%)	28 (68%)	8 (20%)	32 (78%)	B
IV	16	5 (31%)	11 (69%)	8 (50%)	8 (50%)	A
Total	125	43 (34%)	82 (66%)	39 (31%)	83 (66%)	
Note: *There were three students who didn't reveal their gender.						

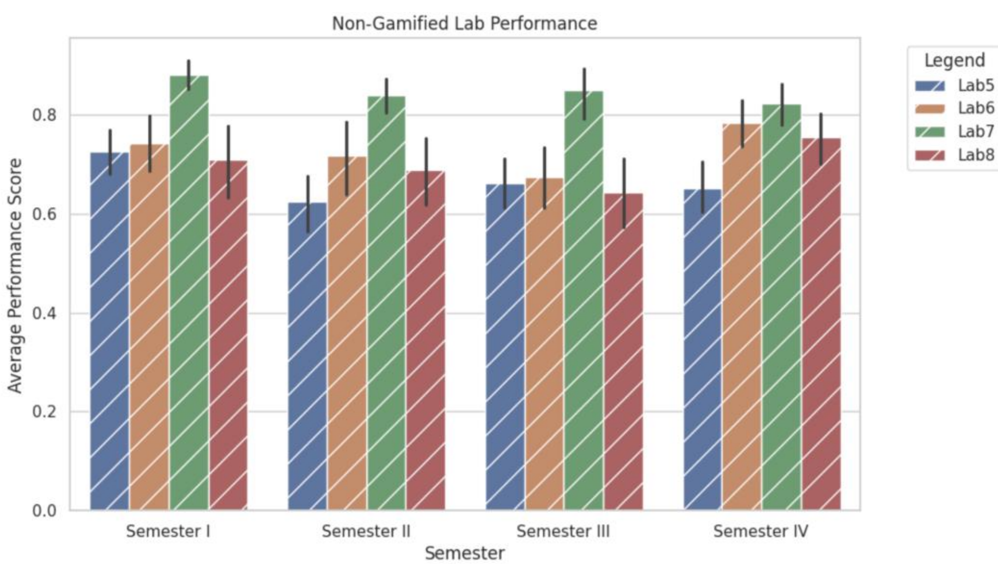
3.2 Data Collection and Analysis

To evaluate the impact of gamified versus non-gamified lab environments on student performance, as well as the variability across different semesters, we utilized an Analysis of Variance (ANOVA) test. This method allows us to determine whether there are statistically significant differences between group means and provides insights into the effectiveness of gamification in educational settings. The two independent variables are the semester and the lab setting (gamified or non-gamified). The semester variable accounts for the different cohorts of students and instructors across the study period. Various instructors, including one author of this study, have taught the course in different semesters, introducing a potential variable in the teaching approach and interaction with students. This variability is incorporated into our analysis to ensure a comprehensive understanding of the factors influencing student learning outcomes.

The dependent variable in our analysis is the student learning outcome. To evaluate the learning outcomes of each lab, students' understanding and retention of the material are assessed through a two-tiered approach. One week after each lab, students complete a quiz designed to gauge their immediate grasp of the lab content. This quiz serves as an initial indicator of how well the students have absorbed the lab material in the short term. Approximately one month following the lab, their knowledge is further evaluated through specific exam questions that are relevant to the lab topics. This subsequent assessment aims to measure the durability of their learning and their ability to integrate and apply the lab concepts over a longer period. Figure 3 shows the students' average performance score calculated based on the quiz score and exam score across four semesters: subgraph (a) displays the results for gamified labs, while subgraph (b) pertains to non-gamified labs. Figure 3 illustrates that students generally achieve better learning outcomes in gamified labs, especially in Labs 1, 2, and 4, compared to non-gamified ones. However, there is a noticeable dip in scores for Lab 3 among the gamified labs. This discrepancy could be attributed to Lab 3 covering a variety of network protocols, which demand that students apply and integrate deeper critical thinking and analytical skills across different network datasets.



(a) Gamified Labs



(b) Non-Gamified Labs

Figure 3. Learning Outcomes of Gamified Labs and Non-Gamified Labs Along the Semesters

3.3 Results

The ANOVA results, shown in Table 4, reveal that the semester, representing variations in student cohorts and instructors, does not significantly impact learning outcomes. It suggests consistency in student performance across different semesters regardless of these changes. However, the significant effect of gamification indicates that incorporating gamified elements into the lab settings positively influences student learning. Additionally, the significance of the interaction between gamification and semester suggests that the impact of gamification on learning outcomes varies across different semesters. It indicates that the effect of being a particular semester varies depending on the gamification setting. This suggests that the impact of the differences between student groups and instructors among semesters on the dependent variable is not uniform across all gamification settings but depends on the specific setting they are in. Therefore, the finding highlights that while gamification generally benefits learning, its impact can vary, potentially due to differing semester-specific contexts.

Table 4. ANOVA Results on the Effects of Semester and Gamification on Learning Outcomes.

Source of Variation	Sum of Squares	DF	Mean Square	F	p-value
Semester	0.036	3	0.012	0.403	0.751
Gamification	2.076	1	2.076	70.591	0.000*
Semester * Gamification	0.726	3	0.242	8.233	0.000*
Within	25.847	879	0.029		
Total	28.685	886			

4 Study 2: Hypothesis Development and Testing

4.1 Relevant Theories

The second study is designed to investigate the learning process of students who engage with various cybersecurity topics through gamified labs and explore the factors that impact their learning outcomes and career interests. We conducted a thorough review of the literature in game design, motivation theory, and theory of career interest to develop our research model.

4.1.1 Game Design

Game design is crucial because it directly affects its ability to engage and motivate users. Game design refers to the overall structure and content of the game, such as its narrative, theme, characters, and aesthetics. The study conducted by Van Staalduinen and De Freitas (2011) proposes that a well-designed game should be engaging and motivating, have clear goals and objectives, provide feedback and rewards, and be appropriately challenging. Similarly, research has shown that the inclusion of feedback and rewards in game design can improve learning outcomes (Kapp, 2012). Moreover, the use of narrative in game design has been found to enhance engagement and learning outcomes in educational games (Ritterfeld et al., 2009). Therefore, well-designed games are expected to have a positive impact on students' learning outcomes. Specifically, the literature on game design suggests that certain game design elements must be present to ensure learning outcomes.

Cognitive load theory proposes that the way information is presented to learners can impact learning (Paas et al., 2003). This theory suggests that cognitive load can either enhance or impair learning, and there are three types of cognitive load: intrinsic load (the inherent complexity of the task), extraneous load (caused by factors not relevant to the learning task), and germane load (related to the learning process). Gamification, particularly the competitive element, can impact the cognitive load of learners, which can affect their learning outcomes. Competitive elements can create additional extraneous load for learners, such as pressure and stress, which can interfere with the learners' cognitive processing of the intrinsic load, negatively impacting learning outcomes. However, the level of competitiveness can also impact the germane load. A moderate level of competitiveness can increase learners' engagement, attention, and motivation, positively affecting the germane load and thus their learning outcomes. A study conducted by Turan et al. (2016) found that when a gamified task is highly complex and moderately competitive, gamification reduces cognitive load, which improves learning outcomes. It suggests that competition increases the intrinsic load and decreases the extraneous load, leading to improved learning outcomes. However, the level of competitiveness needs to be balanced to avoid overwhelming learners with cognitive load, which can negatively affect learning outcomes.

4.1.2 Motivation Theory

Motivation is a crucial part of the learning process. Research has shown that motivation plays a significant role in academic achievement (Lepper et al., 2005; Harter & Connell, 1984; Henderlong & Lepper, 1997). Encouraging students to enjoy learning and participate in the learning process is crucial to achieving good learning outcomes. Anderson and Krathwohl (2001) proposed a model of learning objectives that distinguishes different levels of intellectual behavior in learning. The model was revised from the original one proposed by Bloom (1956). The ability to achieve higher levels of learning objectives is directly related to a learner's autonomous learning efforts, and motivation plays a crucial role in this regard.

Self-determination theory (SDT) (Deci & Ryan, 2013; Ryan & Deci, 2000) suggests that people tend to behave in line with their desires and needs. In this sense, the learner's desire to seek psychological self-growth, influenced by educational contexts, can impact the learning process. According to SDT, there are two main forms of motivation: intrinsic motivation and extrinsic motivation (Deci & Ryan, 2013). Extrinsic motivation refers to doing something for a separate consequence, while intrinsic motivation refers to doing something out of an innate interest or satisfaction (Ryan & Deci, 2000). In a gamified cybersecurity lab, both intrinsic and extrinsic motivation can play a significant role in students' learning process. By leveraging gamification principles, instructors can tap into students' intrinsic motivation, making them more engaged and invested in the learning process. At the same time, extrinsic motivators, such as rewards and recognition, can encourage students to complete tasks and attain learning objectives.

4.1.3 Theory of Career Interest

According to research, an individual's career choices are influenced by three essential factors: interests, self-efficacy expectations, and stable dispositional tendencies (Lent et al., 1994). Understanding how personal characteristics and circumstances affect career interests is critical. The career theory was further applied and supported in the cybersecurity field by a study of participants from the National Cyber League competition, which found that those already skilled in cybersecurity tasks had their interests mainly increased by participating in the competition (Tobey et al., 2014). Another study highlighted that an individual's background knowledge of cybersecurity is a crucial factor that makes maintaining interest after competitions challenging, particularly in competitions with high knowledge barriers (Cheung et al., 2012). Additionally, a comprehensive study of the profiles of cybersecurity competition participants showed that individuals with high perceived self-efficacy in cybersecurity tasks, rational decision-making styles, and investigative interests were more likely to pursue a cybersecurity career after the competition (Bashir et al., 2017). Therefore, it is evident that an individual's skills, knowledge, and interests play a significant role in shaping their career choices in the cybersecurity area, therefore, it is necessary to investigate how gamified cybersecurity labs can affect students' career interests.

4.2 Study Design

Based on the theoretical frameworks, we developed a research model that takes into account the key elements of students' learning process when engaging in gamified cybersecurity labs, as displayed in Figure 4. We provide a detailed description of the proposed model and its hypotheses below.

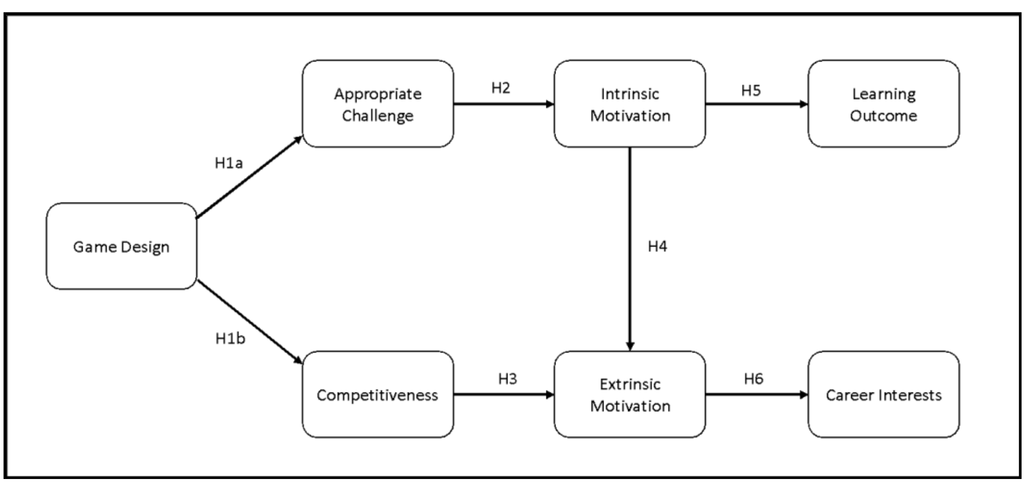


Figure 4. The Proposed Model

Studies have shown that the design of a game can significantly influence the effectiveness of the gamified learning process. Game design elements such as feedback, points, badges, challenges, and rewards, can create a sense of accomplishment and progression, encouraging students to keep engaging with the task. This, in turn, increases student perception of appropriate challenges in gamified learning, resulting in higher levels of engagement and retention of the material being taught. Research conducted by Van Staalduinen and De Freitas (2011) has highlighted the close relationship between good game design and effective instructional design, with effective game design leading to better learning outcomes. Additionally, studies such as Hamari et al. (2014) have shown that effective game design can increase learner engagement and motivation, positively impacting cognitive load. Therefore, we can expect that the more effective the game design, the better the students perceive the appropriate challenge. Therefore, we come up with a hypothesis as follows:

H1a: Game design positively affects the player's perception of appropriate challenges in a gamified cybersecurity lab learning process.

It can also be argued that certain elements of game design can reinforce competitiveness in gamified tasks. These elements include features like leaderboards, badges, points, and rewards for high performance. For example, leaderboards display the rankings of players based on their scores or achievements, which can encourage learners to compete with one another to reach the top position. Similarly, badges and points systems can create a sense of achievement and progress, motivating learners to keep working towards the next level of accomplishment. Rewards for high performance, such as virtual items or special privileges, can also incentivize learners to compete with each other and strive for better performance. The level of competitiveness has an impact on students' learning outcomes. Therefore, it can be expected that the presence and depth of key game design elements can reinforce or reduce the level of competitiveness in gamified tasks, which in turn impacts students' learning outcomes. Therefore, we come up with a hypothesis as follows:

H1b: Game design positively affects the player's perception of competitiveness.

An appropriate amount of challenge in the cybersecurity labs positively affects intrinsic motivation. It is well-known that people tend to engage in activities that allow them to develop skills and feel a sense of accomplishment. The theory of flow, developed by Csikszentmihalyi (1990), emphasizes that the right level of challenge is crucial for people to become fully immersed in an activity. When a task is too easy, learners tend to find it uninteresting, while tasks that are too difficult can be frustrating. In gamified cybersecurity labs, learners can experience intrinsic motivation when they overcome challenges that are embedded in the game. This can lead to a sense of accomplishment and greater motivation to engage in the activity. Therefore, a gamified activity will be more effective if it includes an appropriate level of challenge that offers an uncertain outcome. Therefore, we come up with a hypothesis as follows:

H2: Perception of appropriate challenge positively affects the player's intrinsic motivation in a gamified cybersecurity lab learning process.

Individuals tend to evaluate their own performance by comparing themselves with others, which is also applicable in gamification. According to Liu et al. (2013), the level of competition in a game can influence a player's behavior and emotional response. In educational games, competition among students can increase their motivation and engagement by affecting how they compare themselves to their peers. A leaderboard can further enhance this effect by providing a visual tool for comparisons. The higher the level of competitiveness, the greater the drive among students to outperform their peers, thereby enhancing their motivation. Conversely, reduced competitiveness can lead to disinterest and lower engagement. The motivation for this process is mostly extrinsic as it is driven by visible rewards such as recognition and higher grades. Therefore, we come up with a hypothesis as follows:

H3: Perception of competitiveness positively affects the player's extrinsic motivation in a gamified cybersecurity lab learning process.

In previous studies including Fagan et al. (2008), researchers have attempted to delve into the relationship between intrinsic motivation and extrinsic motivation in various contexts. Through their research, they found that intrinsic motivation has a positive impact on extrinsic motivation. This finding is in line with psychological theories that indicate intrinsic motivation enhances perceptions of extrinsic motivation (Venkatesh et al., 2002). Essentially, the more a person is internally motivated to engage in an activity, the more likely they are to find value in external rewards or recognition related to the activity. Building on these previous studies, we have developed a hypothesis that we believe will help us further understand the relationship between intrinsic and extrinsic motivation in the gamified learning process. Therefore, we come up with a hypothesis as follows:

> **H4: Intrinsic motivation positively affects the player's extrinsic motivation in a gamified cybersecurity lab learning process.**

Intrinsic motivation, which refers to the internal drive to engage in an activity for the sake of personal interests, has been found to be strongly associated with performance, according to previous research (Tauer & Harackiewicz, 2004). This is because individuals who are intrinsically motivated are more likely to concentrate on the task at hand and develop new skills to improve their performance. Furthermore, intrinsic motivation has been identified as an important factor in academic achievement, particularly over a longer period (Tauer & Harackiewicz, 2004). In other words, students who are motivated by their personal interests and values are more likely to achieve academic success compared to those who are motivated by external factors like rewards or punishments. Based on these findings, it can be inferred that intrinsic motivation would be beneficial in the context of game-based learning. In game-based learning, learners' natural curiosity and desire to explore can be harnessed to facilitate the learning process. When learners are intrinsically motivated, they are more likely to be engaged in the learning process, absorb more information, and retain it for a longer period. Therefore, by creating a learning environment that fosters intrinsic motivation, educators can help learners achieve better learning outcomes in the game-based learning process. Therefore, we come up with a hypothesis as follows:

> **H5: Intrinsic motivation positively affects the player's learning outcome in a gamified cybersecurity lab learning process.**

Previous studies, such as Druckman (1995), have shown that games can be an effective tool in enhancing motivation and generating interest among students toward the subject matter. The benefits of using games as a teaching tool include increased engagement, better retention of information, and the opportunity to practice problem-solving skills in a safe environment. Furthermore, it has been noted that career exploration is a continuous process that evolves throughout an individual's life rather than being a static state with a definitive endpoint, as highlighted by Blustein (1997). Extrinsic motivation focuses on the external value expected by doing an activity, which is contrasted to intrinsic motivation, which focuses on the enjoyment of doing the activity itself. Therefore, we anticipate that the use of games will enhance students' extrinsic motivation, leading to an increase in their interest and future benefits expected from working in cybersecurity. This, in turn, will have a positive impact on their career aspirations and increase the likelihood of pursuing a career in cybersecurity. By creating a positive learning experience, we can encourage students to develop a passion for cybersecurity and set them on a path toward a successful and fulfilling career. Therefore, we come up with a hypothesis as follows:

> **H6: Extrinsic motivation positively affects the player's career interests in a gamified cybersecurity lab learning process.**

4.3 Data Collection

To analyze the effectiveness of the proposed model, surveys were conducted among students who participated in Study 1 over the four semesters (Table 3). After playing each game, the students were asked to complete a survey measuring the research constructs related to their game-playing experience. Participating students were given small bonus credits toward their course grades, which motivated most students to thoughtfully and thoroughly complete the surveys. Initially, we collected surveys from 125 students who consented to participate in our study.

The proposed research model included defining all constructs and variables and preparing the measurement items for data collection through a survey. Appendix B provides details of the construct measurement items. Most measurement instruments were adopted from existing literature, but some items were modified to suit the study's purposes. Since the survey data was collected across six gamified lab exercises, the measurement outcomes were combined for each player and analyzed based on the proposed research model. Along with relevant latent constructs, individual students' exam performance for specific questions relevant to the topics was also measured to determine the learning outcomes for each lab exercise.

4.4 Data Analysis and Results

Partial Least Squares - Structural Equation Modeling (PLS-SEM) was used to analyze data and test proposed models. PLS-SEM is commonly used in Information Systems research to analyze direct, indirect, and interaction relationships between constructs that are measured by multiple items (Venkatesh, 2000; Hair et al., 2014). PLS-SEM has become increasingly popular in recent years, with Goodhue et al. (2012) reporting that 49% of path analysis studies published in ISR, JMIS, and MISQ from 2006 to 2010 used this technique. The main advantage of PLS-SEM is its robustness against measurement and sample size issues, making it ideal for exploratory research and theory development (Hair et al., 2010; Gefen et al., 2011; Hair et al., 2014). To evaluate the research model, this study employed SmartPLS 4.0, a statistical software package for data analysis. The analysis adopted a two-step approach that examined both the structural model (inner model) and the measurement model (outer model). First, factor loadings were analyzed to establish convergent validity. The analysis result shows all factor loadings exceeded 0.5, indicating strong convergent validity as Hair et al. (2017) recommended. Second, average variance extracted (AVE) was used to further assess the convergent validity of the constructs in the measurement model. All the AVE values in the measurement model are above 0.6, which supports the convergent validity. In addition, composite reliability (CR) was used as a criterion for establishing convergent validity. The measurement model of the analysis shows all the CR values are above 0.7, which supports the convergent validity of the measurement model (Hair et al., 2014). Table 5 presents the details of the construct measurement results.

Table 5. The Details of the Construct Measurement Items

	Cronbach's alpha	Composite reliability (rho_a)	Composite reliability (rho_c)	AVE
Appropriate Challenge	0.907	0.908	0.956	0.915
Career Interests	0.849	0.853	0.898	0.688
Competitiveness	0.959	0.960	0.970	0.891
Extrinsic Motivation	0.974	0.974	0.978	0.866
Game Design	0.967	0.967	0.973	0.858
Intrinsic Motivation	0.975	0.976	0.977	0.783

To evaluate discriminant validity, the Fornell-Larcker's criterion approach was utilized (Fornell & Larcker, 1981). This criterion examines the square root of the AVE for each construct and compares it with the correlations between the constructs. Table 6 shows that the diagonal values in the same row and column are greater than all other values of the data analysis model. This indicates that the measures demonstrate discrimination and support their respective constructs.

Table 6. The Fornell-Larcker Criterion Results

	Appropriate Challenge	Career Interests	Competitiveness	Extrinsic Motivation	Game Design	Intrinsic Motivation	Learning Outcome
Appropriate Challenge	0.957						
Career Interests	0.529	0.830					
Competitiveness	0.789	0.485	0.944				
Extrinsic Motivation	0.824	0.493	0.809	0.930			
Game Design	0.902	0.478	0.751	0.791	0.926		
Intrinsic Motivation	0.857	0.540	0.721	0.830	0.799	0.885	
Learning Outcome	0.225	0.073	0.229	0.176	0.254	0.242	1.000

Once the measurement model was examined and ensured to have convergent and discriminant validity, we performed the structural model analysis. First, to check the degrees of correlations between the independent variables, we examined the variance inflation factor (VIF) values. The results are demonstrated in Table 7. The VIF values of the structural model vary from 1 to 2.179, which is within the recommended range.

Table 7. The VIF Values of the Structural Model

	VIF
Appropriate Challenge -> Intrinsic Motivation	1.000
Competitiveness -> Extrinsic Motivation	2.081
Extrinsic Motivation -> Career Interests	1.000
Game Design -> Appropriate Challenge	1.000
Game Design -> Competitiveness	1.000
Intrinsic Motivation -> Extrinsic Motivation	2.081
Intrinsic Motivation -> Learning Outcome	1.000

Using SmartPLS 4.0, we conducted structural modeling to find the path coefficients, R-squared, and the p-value of the model. The result of the structural model analysis is detailed in Table 8 and the model fit is presented in Table 9.

Table 8. The Results of the Structural Model Analysis

	Original sample (O)	**Sample mean (M)**	**Standard deviation (STDEV)**	**T statistics (|O/STDEV|)**	**P values**
Appropriate Challenge -> Intrinsic Motivation	0.857	0.855	0.040	21.674	0.000
Competitiveness -> Extrinsic Motivation	0.439	0.427	0.094	4.691	0.000
Extrinsic Motivation -> Career Interests	0.493	0.502	0.065	7.586	0.000
Game Design -> Appropriate Challenge	0.902	0.900	0.028	32.198	0.000
Game Design -> Competitiveness	0.751	0.749	0.054	13.849	0.000
Intrinsic Motivation -> Extrinsic Motivation	0.514	0.526	0.089	5.792	0.000
Intrinsic Motivation -> Learning Outcome	0.242	0.239	0.082	2.966	0.003

Table 9. The Model Fit Summary of the Structural Model

	Saturated model	**Estimated model**
SRMR	0.060	0.084
d_ULS	2.383	4.671
d_G	3.970	4.300

Chi-square	2268.401	2304.377
NFI	0.713	0.708

Based on the structural model analysis, we could find that all the hypotheses in the proposed research model are statistically supported as summarized in Figure 5. Moreover, it is found that the amount of variance accounted for most of the constructs is quite high for the meditating constructs (i.e., appropriate challenge, competitiveness, intrinsic motivation, and extrinsic motivation) varying from 56.4% to 81.3%, but for the consequent constructs' R-squared values are relatively low. For instance, the career interest of the students has an R-squared value of about 24.3%, whereas that for the learning outcome is only about 5.8%. These findings suggest that while the model effectively captures the mediating factors, additional variables may influence the final outcomes, particularly in terms of career interest and learning outcomes.

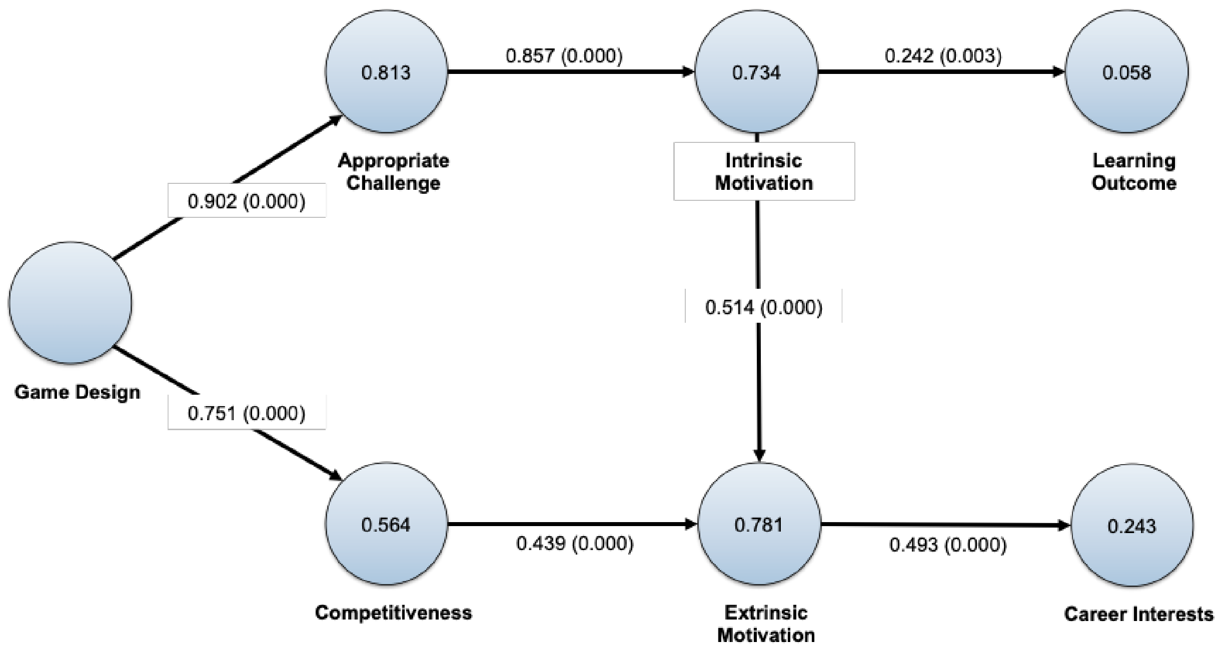


Figure 5. The Structural Model

5 Study 3: Interview Study

5.1 Study Design

In the first two studies, we employed quantitative methods to analyze survey and learning outcomes data to understand students' performance and gamification's impact on their motivation, learning outcomes, and career interests. Building upon these insights, Study 3 pivots towards an in-depth exploration of qualitative data derived from interviews with students who engaged in gamified lab activities. The objective is to unravel the students' learning experiences by focusing on their perceptions, motivations, and challenges encountered in the gamified learning environment. This qualitative exploration is pivotal for crafting a comprehensive view of gamification's influence on cybersecurity settings. It seeks not only to complement the quantitative findings of the earlier studies but also to surface the rich, subjective narratives that numbers alone cannot convey. By employing a phenomenological approach to the analysis (Moustakas, 1994), this part of the work aims to capture the essence of the students' experiences, thereby offering valuable insights that could potentially guide future gamification strategies.

5.2 Data Collection

5.2.1 Participant Selection and Recruitment

Participants in this study were exclusively drawn from the pool of students enrolled in cybersecurity-related courses with gamified lab components at the end of each semester. To ensure a diverse representation of students' experiences, no specific demographic criteria were employed in the selection process. The recruitment process commenced with email invitations, introducing the study's objectives and highlighting the voluntary nature of participation. Students who expressed interest and provided consent were officially enrolled as study participants, forming the foundation for subsequent data collection through interviews. We recruited 15 students for the interview study. Figure 6 shows the learning outcomes of interview participants, evaluated by follow-up quiz and exam performance, compared to all participants in Study 1, in both gamified and non-gamified labs. The figure shows that the performance of interview participants is distributed across a wide range, similar to the overall distribution of all participants. The diversity of outcomes observed indicates that the interview participants are representative of the broad population.

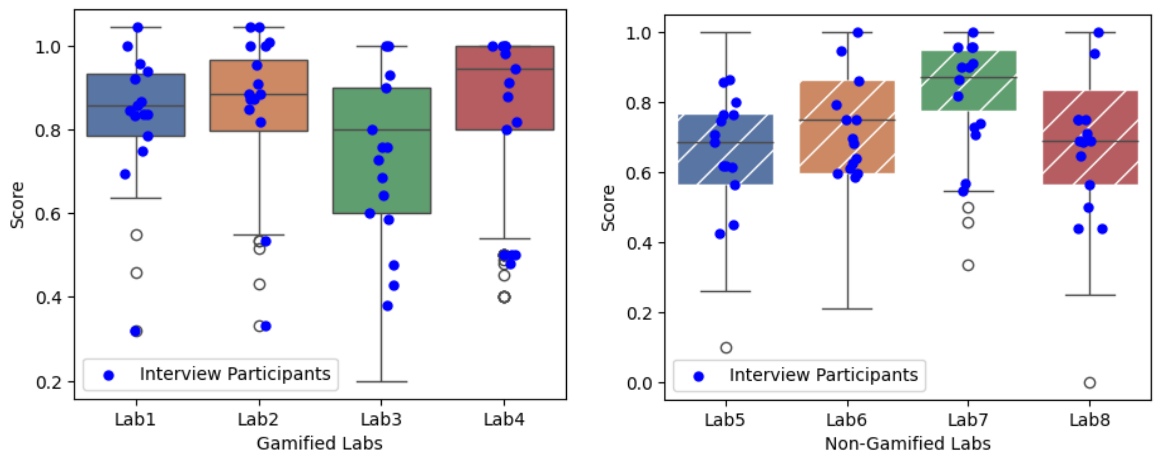


Figure 6. Learning Outcomes of Interview Participants Compared to all Participants in Study 1, in both Gamified and Non-Gamified Labs

5.2.2 Interview Setting and Protocol

Interviews for this research were conducted in a semi-structured format and facilitated through Zoom video conferencing platforms. This approach was chosen to prioritize convenience and accessibility for participants. A question list was prepared to ensure consistency and thoroughness. The majority of the interview questions were open-ended, which allowed participants to provide detailed and candid responses, thus facilitating a rich and nuanced exploration of their experiences within gamification labs. The interview protocol is detailed in Appendix C.

5.3 Data Analysis

The analytical approach adopted for this study is rooted in phenomenology, a qualitative research method that seeks to explore and understand the essence of human experiences by examining the lived experiences of individuals and focusing on their subjective interpretations and perceptions (Moustakas, 1994). This methodological framework includes open-ended and exploratory analysis. This phenomenological approach is well-suited for our research, as it allows for an in-depth exploration of the participants' experiences with gamification labs.

Prior to analyzing the collected data, we engaged in epoche, a phenomenological method aimed at bracketing out preconceived notions and biases to approach the data objectively (Moustakas, 1994). This step is crucial to ensure that our analysis is based solely on the participants' experiences, free from any preconceived expectations about gamification. Each interview was recorded and transcribed verbatim to ensure the capture of participants' precise expressions. Additionally, to safeguard the privacy and confidentiality of the participants, we conducted data anonymization. Subsequently, through in-depth reading and analysis of these transcripts, we gained an initial understanding of the data and focused on the subtle differences expressed by the students and the context behind their words. This process enabled us to comprehensively understand the participants' viewpoints, feelings, and experiences, laying a solid foundation for subsequent analysis and interpretation (Bevan, 2014). After each reading, reflective journaling was used to document immediate reactions and insights (Ortlipp, 2008). This practice not only fosters a deeper connection with the data but also allows significant statements and initial thematic ideas to emerge. Utilizing insights from journaling and initial readings, we employed narrative synthesis to interconnect these insights across interviews, highlighting shared themes and experiences. This synthesis culminated in extracting the core essence of students' experiences with gamification, capturing its fundamental impact on their learning and engagement.

5.4 Findings

Building on phenomenological data analysis, several key themes emerged from students' experiences with gamification labs. These themes offer valuable insights into how gamification influenced their motivation, learning, and overall experience. Each theme is supported by direct participant quotes and insights derived from reflective journaling throughout the analysis process. We first extracted themes from the reflective notes and then further aggregated them. Table 10 summarizes the aggregated themes along with the first-order themes. This combination of narrative synthesis and reflection provided a deeper understanding of the student's experiences.

Table 10. The Themes Identified from Interview Responses (the Complete Results and Respondents' Quotes can be found in Appendix D)

Aggregated Themes	First-Order Themes, Reflection Notes
Appropriate Challenge and Competitiveness: This theme explores how game design elements like leaderboards and instant feedback can motivate students while also providing appropriate levels of difficulty to foster critical thinking.	**Learning Process:** Participants appreciated the step-by-step guidance in gamified labs, indicating that clear instructions help in understanding complex tasks.
	Preference for Instant Feedback: Students preferred interactive labs over traditional ones, as they provided instant feedback on their scores and positions on the leaderboard.
	Competitive Motivation: Leaderboards motivated participants to excel, suggesting that competition can enhance engagement and effort.
Students' Experience and Accessibility: This theme focuses on how game design elements improve the ease of following instructions for better navigation, adapt to students' diverse needs for visual aids, and enhance accessibility from different devices.	**Ease of Following Instructions:** Participants preferred instructions that were broken down into smaller web pages rather than a large document for easier navigation.
	Visual Learning Aids: Visual learners found the instructions and challenges with visual aids, such as instructional diagrams, demonstration screenshots, and images of challenges, to be helpful.
	Learning Style Considerations: The preference for visual and gamified elements highlights the need to accommodate diverse learning styles.
	Preference for Accessible Materials: Participants appreciated the web-based platform's ability to provide easy access from different devices.
Enhanced Motivation: This theme examines how clear instructions, visual aids, and gamification strategies can motivate students and support	**Alignment of tasks with contextual mission descriptions and instructions:** Gamified labs were found more enjoyable and engaging when the tasks were aligned with contextual mission descriptions.
	Enjoyment and Learning: Participants enjoyed the gamified labs, which suggests that enjoyment can

their learning efforts.	enhance the learning experience.
	Interplay of Intrinsic and Extrinsic Motivations: Participants' feedback revealed a dynamic interplay of intrinsic and extrinsic motivators within gamified learning settings.
Students' Learning and Career Interests: This theme explores how educational tools and strategies can align with students' career goals and personal interests, enhancing the relevance and practical application of their learning experiences.	**Practical Application of Knowledge:** Gamified labs provided practical real-world examples, enhancing the relevance and application of theoretical concepts.
	Critical Thinking in Gamified Labs: Some participants felt gamified labs encouraged critical thinking, highlighting the value of interactive challenges.
	Independence in Learning: Gamification encouraged independent learning, as students sought out additional resources to improve their scores.

5.4.1 Appropriate Challenge and Competitiveness

Learning Process: The structured design of gamified labs, characterized by detailed step-by-step instructions followed by practice tasks, was highly appreciated by students. Unlike the traditional lab instructions, which were typically delivered as a large, dense document (either in Word or PDF format), the gamified labs broke down the entire lab into a series of smaller, manageable challenges. As a result, students were only provided with a focused section of instructions relevant to the specific challenge they were working on at the time. This segmented structure allowed them to focus on a small challenge at a time and made the learning process less overwhelming. Students found this step-by-step structure more learner-friendly and enabled them to thoroughly understand and apply concepts at their own pace, even when the lab is conducted in the classroom setting. A student stated, "*It provides step-by-step instructions on what you're doing and why you're doing it. So there's more understanding and more knowledge being earned and learned at the same time.*" Students mentioned they had less pressure on grades while making progress in each challenge in an organized manner. Another student commented, "*[In tasks with step-by-step instructions], you get to respond with a second chance*." This reflects an enhanced learning experience where the fear of immediate failure is mitigated.

Preference for Instant Feedback: The provision of instant feedback within these labs plays a crucial role in sustaining motivation. Students expressed a strong preference for immediate validation of their actions, with one stating, "*answering all the questions correctly is important, it was also very important to get the notification of the result that it worked."* This instant feedback mechanism is pivotal in reinforcing learning and rewarding effort, as another participant noted, "*I like the instant feedback... I thought it was very rewarding to get the notification and see the result that it worked.*" The immediate satisfaction from earning points or achieving a task further fuels student motivation, blending intrinsic desires for personal accomplishment with extrinsic rewards. For example, one student stated, "*I had that satisfying feeling at the moment of earning the points."*

Competitive Motivation: We found the element of storytelling within game tasks adds a layer of competitiveness and realism to the learning process. Students felt that this aspect made the scenarios feel applicable to real-world situations, thereby increasing their motivation to learn. For instance, one student stated, "*It makes me feel more real in the sense that I could use this one day, I feel like it really draws attention and like the desire to learn it because it forces you to learn to solve a problem."*

The leaderboard feature also played a crucial role in fostering a competitive atmosphere, especially among students who were keen on monitoring their progress relative to others. Many students highlight the motivational catalysts that leaderboard serves as an important competitive aspect. One student commented, *"It does because [the leaderboard] makes you want to be on top."* Another student further highlighted the instant gratification and motivation driven by real-time feedback and rewards, "*It's like a real-time game, and you immediately see the changes [of points] after solving a task."*

These findings support hypothesis H1a that game design enhances the perception of appropriate challenges and H1b that it boosts the sense of competitiveness among players. Furthermore, they affirm H2 and H3 by demonstrating that the perception of challenge positively impacts intrinsic motivation, while the perception of competitiveness enhances extrinsic motivation.

5.4.2 Students' Experience and Accessibility

Ease of Following Instructions: Students' experiences with the gamified labs also reflect a strong appreciation for the step-by-step organization of the game challenges, which made the labs more intuitive and user-friendly. The fine-grained structure allowed students to navigate the materials with ease. By breaking down the lab into smaller, manageable tasks, students felt the content was more accessible. One student commented, "*It's easy to navigate. It's easy to understand. It's very user-friendly," and "It's smaller pieces, so it's easier to take a pause.*" We found this design also supports students in managing their time more effectively since the modular nature of the labs allows them to access the learning materials using small chunks of time. For example, one student commented, "*for example, when I had a 10 min break. I felt I was able to do maybe one task when waiting between classes.*"

Visual Learning Aids: Unlike traditional lab formats, the gamified labs incorporated more visual aids, such as screenshots, diagrams, and visual icons relevant to the current task, which helped reinforce key concepts. As one student mentioned, "...*Having those screenshots helped keep me engaged.*" The use of visuals also made the labs more appealing and the learning experience more enjoyable. A student stated, "*It made the labs feel less like homework and more like little puzzles to figure out."*

Learning Style Considerations: The inclusion of rich visual content within the gamified labs particularly benefits students with a visual learning preference. For example, a student remarked, "*I'm a visual learner, so having a lot of screenshots in the material was really helpful."* Furthermore, students who prefer to learn and read at their own pace can take advantage of the modular structure of the labs. It is also easy for reflective learners to take a pause or navigate in the gamified lab. A student commented, "*It made the labs feel less like homework and more like little puzzles to figure out."* This approach underlines the importance of incorporating diverse learning modalities into educational design to cater to different learning styles, thereby enhancing comprehension and retention of information.

Preference for Accessible Materials: The delivery of gamified labs via a web-based platform significantly enhances accessibility, allowing students to engage with materials not just from computers, but also via mobile devices like phones and tablets. This flexibility was highlighted by one student who noted, "*I was able to access it on my phone or my iPad.*" Such accessibility ensures that students can utilize moments outside the traditional classroom environment to advance their learning, thereby integrating education more seamlessly into their daily lives.

5.4.3 Enhanced Motivation

Alignment of Tasks with Contextual Mission Descriptions and Instructions: The integration of gamified elements in educational labs has shown a significant impact on student motivation, particularly through the alignment of tasks with contextual mission descriptions and instructions. This game design enables students to see the relevance of their activities, enhancing their engagement by linking practical tasks directly to underlying concepts. One participant emphasized the effectiveness of this approach, noting, "*For me, learning by doing is very interesting. You learn something new while doing labs."*

Enjoyment and Learning: This method of active, hands-on learning is not only more engaging but also more enjoyable, as students favor interactive and gamified activities over traditional learning methods. As another student shared, "*The gamified labs were a lot more interesting and easier to understand*," highlighting the added value of practical engagement.

Interplay of Intrinsic and Extrinsic Motivations: Students' feedback also reveals a dynamic interplay of intrinsic and extrinsic motivators within gamified learning settings. According to Study 2, this dual nature of motivation underscores the potential of gamified educational designs to foster not just academic success, but also a genuine enthusiasm for learning. In the interview, we asked all participants to rank the factors that drive their motivation when completing the gamified labs. The options included: (a) finishing the lab quickly, (b) learning more concepts, (c) answering all questions correctly, (d) improving ranking on the leaderboard, and (e) an "Other" category for additional preferences. Some participants specified "Other" preferences, including "storytelling" and "real-world examples."

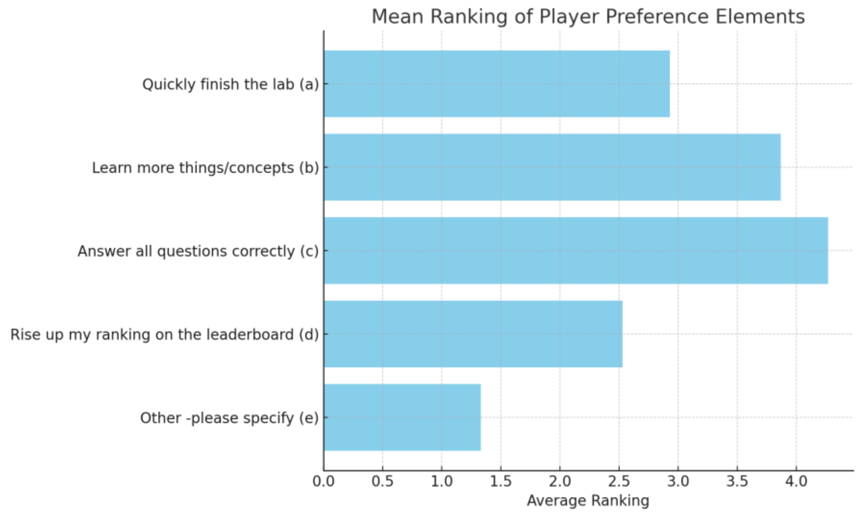


Figure 7. Ranking of Factors Driving Student Motivation in Gamified Labs

We assigned numerical values for analysis, with a score of 5 for the most important factor and 1 for the least important. The ranking results in Figure 7 provide fresh insights into player preferences within the gaming environment. The highest ranking for "Answer all questions correctly" at 4.27 indicates a strong preference among students for games that test their knowledge and problem-solving skills. The value placed on "Learn more concepts" with an average ranking of 3.87, demonstrates students' enthusiasm for games that provide educational value. This aligns with the growing trend of leveraging gaming as a learning tool. "Quickly finish the lab" received an average ranking of 2.93, indicating that while students value efficiency and the ability to complete tasks promptly, these aspects are deemed less important compared to the aspects of learning. This insight implies that students are willing to invest more time in games that are enriching and intellectually stimulating, as opposed to those that simply prioritize speed. The lower ranking for "Rise up my ranking on the leaderboard" at 2.53 suggests that competitive elements, though recognized and enjoyed, are not the primary drivers of student engagement in this context. It denotes that while competition can introduce excitement and motivation, it should not overshadow the core educational and intellectual elements of the game. "Other - please specify" received the lowest ranking, at 1.33, indicating that the principal motivators for students are aptly captured by the predefined categories. Nevertheless, some students expressed a particular appreciation for "storylines" and "real-world examples". These facets are important for some players and have the potential to augment both engagement and the educational value of the game.

It was also noted that while competitive elements like points and leaderboards are motivating, they need to be thoughtfully balanced with the educational objectives. Considering that competitiveness is not the sole factor impacting extrinsic motivation, overemphasis on competition could detract from learning if not aligned with the educational content. Some students, not driven by competitiveness, found value in other game elements, such as the aforementioned "storylines" and "real-world examples" in the game narratives. For example, one student commented, "*it was very enjoyable … and I always put the storyline at the top three because it's feel storylines is really good for students to follow*." To address a broad range of interests and learning styles, incorporating diverse elements such as compelling storylines and real-world examples can further enhance the gamified experience. By making the game both comprehensive and inclusive, educators can effectively use extrinsic motivators to not only enhance learning outcomes but also inspire students towards future career paths in the field.

5.4.4 Students' Learning and Career Interests

Practical Application of Knowledge: Participants indicated that the gamified lab environments, particularly the real-world applicability of the tasks, substantially increased their interest in pursuing similar work professionally. The design of these labs, which mimic real-world scenarios, helps students visualize how the skills they are acquiring could be applied in practical settings. This connection is strengthened by the gamification elements, such as earning points, which not only serve as immediate rewards but also build confidence in handling real-world challenges. For instance, one student described, "*understanding* *the material and getting like real world examples,..., showing us like what we're learning and how it can be applied.*"

Critical Thinking in Gamified Labs: Gamified labs also fostered critical thinking by challenging students to engage with the material more deeply through interactive problem-solving. This approach encouraged students to think beyond simply following instructions, focusing instead on understanding the "why" behind their actions. A student commented, "*Understanding why is important… it was easy once you grasp the overall concept of what you're doing*." This remark underscores the importance of context and comprehension in facilitating easier and more effective learning experiences. Another student expressed, "*I also really liked that we weren't using a textbook during class and just doing worksheets; instead, we were actually solving something and thinking about it.*" Such intrinsic motivation not only enhances immediate learning outcomes but also encourages a deeper, more enduring understanding of the material.

Independence in Learning: Our findings in Study 2 revealed compelling insights into how intrinsic and extrinsic motivations impact student learning outcomes and career interests, corresponding with hypotheses H5 and H6. The findings emphasize the profound impact of intrinsic motivation on students' learning processes within a classroom setting. Students exhibited a strong drive to understand concepts thoroughly and solve tasks accurately, demonstrating a shift from merely receiving information to actively acquiring knowledge. In the interview, we observed that this transition is crucial for deep learning and was highlighted by students' proactive learning behaviors. For instance, one student mentioned, "*And if there's something I do not understand from the game, I will try to Google it to find answers or related subjects.*" This indicates not only engagement but also an autonomous pursuit of comprehension beyond the structured learning environment.

6 Discussion

6.1 Contributions to Theory and Practice

Our study extends the body of knowledge on the impact of gamification in educational settings, specifically in the field of cybersecurity education. Prior research predominantly focused on gamification's role in cybersecurity extracurricular activities, such as workshops and competitions (e.g., CTFs). Our findings demonstrate that gamification within a classroom setting can significantly enhance learning experience and outcomes. This result expands upon existing educational theories that advocate for active learning environments.

In a study comparing learning outcomes between non-gamified and gamified cybersecurity labs (Study 1), it was confirmed that gamified cybersecurity lab exercises are more effective in helping learners understand various cybersecurity topics. This finding is consistent with prior research suggesting that gamified learning is superior to traditional learning methods in general business education (Faria & Wellington, 2004). The study extends the existing theory by exploring the benefits of gamification in the specific area of cybersecurity education. Cybersecurity education differs from other business educational areas as it deals with highly technical and practical topics that are subject to rapid change due to technological advancements and industry developments. This can make it difficult for cybersecurity educators to maintain their students' interest and engagement in the learning materials. The study sheds light on this field by confirming that gamified cybersecurity labs are an effective way to overcome these challenges.

In the game experience analysis study (Study 2), we delve deeper into the mechanisms of how gamification influences learning by differentiating between intrinsic and extrinsic motivations. The configuration of our model was guided by both theoretical considerations and empirical validation. Our results support the hypothesis that appropriate challenges within gamified learning can bolster intrinsic motivation, which in turn, positively impacts learning outcomes. Similarly, the competitive elements of gamification seem to enhance extrinsic motivation, which we found to be linked to increased career interest among students. These findings highlight how different facets of gamification can cater to diverse motivational needs, thus fostering a more engaging and effective learning experience.

We also found that game elements, namely, game design, appropriate level of challenges, and competitiveness, have significant roles in learners' gamified cybersecurity game experience. Specifically, the research model shows that game design is an antecedent of both appropriate challenge and competitiveness. This confirms that a well-designed gamified learning module is a foremost necessary condition to make the learners feel the game has an appropriate level of challenge and is competitive enough so they focus on the game. In addition, the analysis result shows that an appropriate level of challenge positively influences the intrinsic motivation of the learner, whereas perceived competitiveness influences the extrinsic motivation. This finding tells us different elements of the gamified cybersecurity learning module can work in different ways to enhance the learner's motivation. That being said, gamified game designers should pay attention to various game elements that may influence the learning experience.

Another finding is that learners' learning outcomes and career interests are influenced by different factors. More specifically, the study shows that learning outcomes are significantly affected by intrinsic motivation, whereas career interests are significantly affected by extrinsic motivation. This tells us that intrinsic motivation, which comes from the learner's desire to be better at the given task, helps the learner learn the topics handled in the gamified cybersecurity labs. If learners are intrinsically motivated in the game, they would spend more time/effort to figure out the solutions to get better performance, which eventually enhances the learning outcome. On the other hand, if learners are extrinsically motivated, they would be more interested in the practical rewards that could be obtained by playing the gamified cybersecurity labs. By acknowledging the role of extrinsic rewards in career interests, educators can more effectively guide students in their career choices, ensuring they are aware of the potential rewards and challenges in their fields. One of the practical benefits of the gamified cybersecurity lab could be to put the learners in a realistic situation where they could experience how the cybersecurity techniques are actually applied to the real world. Therefore, those who have high extrinsic motivation can easily find the benefits and be more interested in a cybersecurity career.

In the qualitative exploration of gamified cybersecurity labs (Study 3), we probe deeper into the individual experiences of students to complement the quantitative findings of the previous studies. Through the interview questions related to different aspects of gamified lab design, Study 3 uncovers how gamified learning fosters not only a deeper understanding of cybersecurity concepts but also enhances learning autonomy. Students expressed their preferences for gamification elements such as modular lab instruction design, instant feedback, visual aids, and easy access. Students reported actively seeking out additional resources and employing self-directed learning strategies, indicative of increased intrinsic motivation as highlighted in Study 2. This shift toward autonomy and proactive learning aligns with the findings from Study 1, where gamified labs were shown to be more effective than traditional methods in maintaining student engagement in the dynamically changing field of cybersecurity. Furthermore, Study 3 illuminates the role of visual and hands-on elements in enhancing comprehension and engagement and supporting diverse learning preferences.

In addition, in Study 3, we found that students could use the gamified cybersecurity labs to gain practical experience, which eventually enhanced their career interest in the cybersecurity field. This finding is consistent with the prior literature that claim that business games can reduce the gap between theory and practice in the industry (Kumar & Lightner, 2007; Lin & Tu, 2012). By providing more practical experience, gamified cybersecurity labs can provide practical value to learners in the cybersecurity field.

The competitive dynamics of gamification, as reflected in students' responses to leaderboards, also enhance extrinsic motivation. It reinforces the findings of Study 2, which observed that competition can stimulate career interest. However, in the interviews, not all students are drawn to competition or motivated by leaderboards. Some expressed a preference for engaging with story narratives and other game elements, such as visual aids, over striving for high rankings. This highlights the diverse preferences among students when it comes to competitiveness. Therefore, educators and game designers should focus on creating intellectually stimulating content that provides meaningful learning opportunities. While competitive elements are important for engagement, they need to be balanced with the game's educational goals. Meanwhile, it is also necessary to consider a wide range of player interests by including a variety of game elements such as storylines and real-world examples. By implementing these strategies, gamified labs can provide richer and more diverse learning experiences that not only increase engagement and motivation but also support a wider range of learning styles in cybersecurity education.

From a practical standpoint, our research offers valuable insights for educators and curriculum designers, particularly in the cybersecurity field. The positive reception of gamified learning experiences by students—attributed to factors like improved accessibility, instant feedback, and the breakdown of tasks into manageable challenges—suggests that incorporating gamification into the classroom can be a potent strategy to enhance engagement and learning efficacy. Educators can leverage these insights by integrating appropriate challenges and competitive elements into their teaching methods to stimulate both intrinsic and extrinsic motivations. For instance, creating story-driven narratives and scenarios in cybersecurity education can make the learning process more captivating and relatable, potentially increasing student retention and interest in the subject matter. Moreover, the feedback on instant rewards and task segmentation offers a blueprint for designing educational games or activities that align with students' preferences and learning behaviors. By adopting such approaches, educators can not only improve academic performance but also spark a greater interest in career paths related to the subject matter, thereby contributing to the broader goal of cultivating skilled professionals in the field of cybersecurity. As Robson et al. (2015) suggested, practitioners can also utilize setup, rule, and progression mechanics to shape the gaming environment, establish the goals of the gamified experience, and incorporate various types of experiences to enhance the effectiveness of cybersecurity training. As Reginato et al. (2022) stated, collaboration between academia and business practices can enhance the transfer of knowledge from the classroom to the real world. As a learning method increasingly relevant to the new generation, the importance of gamified learning in cybersecurity education and training is expected to rise. To effectively integrate gamified learning into curricula, particularly in professional training, it is essential to understand how learners perceive gamified learning. This study highlights how cybersecurity education and training can be designed and improved for future generations of learners.

6.2 Limitations and Future Research

Our study has several limitations. One notable constraint is the observed variance in student preferences regarding gamification elements. This variation suggests that a one-size-fits-all approach to gamification may not be the most effective educational strategy, as individual differences can significantly influence the learning experience and outcomes. Moreover, the design of Study 1, where Labs 1-4 are gamified and Labs 5-8 are non-gamified, presents limitations in directly comparing student performance due to potential differences in lab contents. The current design choices were motivated by practical considerations, including differences in instructors, small class sizes each semester, and concerns about grading fairness. If some of these practical constraints are minimized, several alternative experimental settings could be considered to enhance the comparability of gamified and non-gamified labs. Ideally, the gamified and non-gamified versions of each lab should be randomly assigned to participants. This would allow for a direct comparison of student performance under controlled conditions and help mitigate differences in lab difficulty. If random assignment within the same semester is not feasible, implementing gamified and non-gamified versions in parallel sessions could be an alternative. Another option is to offer gamified and non-gamified versions in different semesters if the student body is similar and the instructors are the same.

Additionally, the current research predominantly focuses on the aggregate impact of gamification without delving into how specific components of gamification affect different groups of students. The influence of demographic factors or academic levels on the effectiveness of gamification remains underexplored in our study. Our future research aims to explore the individual differences in gamification learning more thoroughly. Understanding how personal preferences, learning styles, and motivational triggers influence the effectiveness of gamification can inform more personalized and adaptive educational designs. This could also help identify any potential biases or barriers that certain student groups may face in gamified environments.

Furthermore, the scope of our study is limited to a particular educational context and subject area, which may affect the generalizability of our findings. Expanding the deployment of gamified labs across a broader range of classes and demographic groups is another critical avenue for future research. It is worth conducting studies in different types of institutions, such as community colleges, private universities, and international universities, to understand how institutional context influences the effectiveness of gamified labs. Further research should also consider longitudinal studies to assess the long-term effects of gamification on learning and motivation. Such studies could provide valuable information on the sustainability of gamification's benefits and its impact on student's academic trajectories and career interests.

7 Conclusion

In conclusion, the multi-study approach adopted in this research significantly enriches our understanding of gamification's impact on cybersecurity learning. By conducting a comprehensive analysis over four semesters, we thoroughly evaluated how gamification can be woven into cybersecurity learning to enhance student engagement, motivation, career interests, and learning outcomes. Moreover, the multifaceted approach enabled an in-depth exploration of the effects of competitiveness and game design on student motivation, ultimately presenting a holistic view of the transformative potential of gamified learning. This comprehensive perspective not only advances theoretical discussions of gamification in learning but also offers practical insights for educators aiming to integrate effective gamification strategies into educational methodologies, particularly in fields that demand high levels of engagement and critical thinking such as cybersecurity.

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Appendix A: Gamification Literature Review

Table A1. Summary of the Literature Review

Research Theme	Literature	Research Topic	Theoretical Framework	Research Methods	Main Findings
Concepts of gamified learning	Van Eck (2006)	Digital game-based learning	N/A	N/A	It discusses the effectiveness and engagement of DGBL, how its key principles can be applied for implementation, the use of commercial off-the-shelf (COTS) DGBL in classrooms, the impact of DGBL on institutional IT support, and lessons gained from technological innovations in learning.
	Deterding et al. (2011)	Historical origins of the gamification in relation to precursors and similar concepts	N/A	N/A	Gamified applications offer insights into new, game-like phenomena that complement playful behaviors. "Gamification" is defined as using game design elements in non-game contexts.
	Glover (2013)	Overview of gamification	N/A	N/A	When encouraging meaningful learning experiences through gamification, it's important to consider what is suitable for the learners and the context, which is similar to designing learning activities. Gamification should be considered at the design stage. The main factor to assess is the level of intrinsic motivation. Achievable and desirable rewards provide sufficient extrinsic motivation, but should be scarce enough to create a sense of pride and accomplishment.
	Schmidt-Kraepelin et al. (2018)	Taxonomy of gamification concepts for health apps	Taxonomy development method	Taxonomy Development	Taxonomy of gamification concepts for health apps consists of twelve dimensions, each having between two and three characteristics.
Literature review of gamified learning	Susi et al. (2007)	Overview of serious games	N/A	Literature review	Serious games allow learners to experience situations that are impossible in the real world for reasons of safety, cost, time, etc., but they are also claimed to have positive impacts on the players' development of several different skills. The markets in which such games are used include military, government, educational, corporate, and healthcare sectors. Additionally, key players in the North American and European serious games market are identified.
	Young et al. (2012)	Trends in Serious Gaming for Education	N/A	Literature review	Many educationally interesting games exist, yet evidence for their impact on student achievement is slim.
	Hamari et al. (2014)	Literature review of empirical studies on gamification	N/A	Literature review	Gamification can have positive effects, but its impact depends on the context and the users.
	Antonaci et al. (2019)	Effects of Gamification in Online Learning Environments	N/A	Literature review	The application of gamification in online learning, specifically within Massive Online Open Courses (MOOCs), represents a relatively nascent area. It is currently characterized by a dearth of empirical studies and evidence, with a prevailing inclination

Table A1. Summary of the Literature Review

Research Theme	Literature	Research Topic	Theoretical Framework	Research Methods	Main Findings
					towards the utilization of gamification primarily as a mechanism for dispensing external rewards.
	Sailer and Homner (2019)	Meta-analysis of effects of gamification on cognitive, motivational, and behavioral learning outcome	N/A	Meta-analysis	Gamification has small but significant effects on cognitive, motivational, and behavioral learning outcomes. The impact on cognitive learning outcomes remains consistent in high-quality studies, while the effects on motivational and behavioral outcomes are less consistent. Factors such as game fiction and social interaction significantly influence behavioral learning outcomes, and combining competition with collaboration is particularly effective.
	Majuri et al. (2018)	Literature review of gamification of education and learning	N/A	Literature review	Gamification in education and learning often focuses on signaling achievement and progression, with less emphasis on social interaction and immersive experiences. Studies typically concentrate on measurable performance metrics, and the reported results tend to be largely positive.
	Koivisto and Hamari (2019)	Literature review of gamification research	N/A	Literature review	The results generally show that gamification is effective, but there are also many mixed findings. Gamification is most commonly used in education, health, and crowdsourcing, often involving points, badges, and leaderboards. However, research on gamification still needs to be more consistent in its models and variables.
	Dicheva et al. (2015)	Systematic mapping of literature in gamification in education	Systematic mapping design	Literature review	The study maps published work to classification criteria, analyzing the current empirical research on applying gamification to education. It highlights major obstacles and needs, such as the requirement for proper technological support and controlled studies to determine the influence of gamification on learners' motivation. More substantial empirical research is needed to confirm the impact of gamification on motivation.
Design principles of gamified learning	de Feritas and Oliver (2006)	Game-based learning	N/A	Design science	Introducing a four-dimensional framework to help tutors evaluate game- and simulation-based learning and support critical approaches. The framework is applied to two practice examples to test its effectiveness and structure critical reflection.
	Zaman et al. (2012)	Designing concepts for educational mini-games	Human-centred game design process	Design science	There was a divide between two types of mini-games. One type focused on formal language learning, such as vocabulary exercises. The other type centered around communication with other players or in-game characters. Educational mini-games with the potential to be both fun and efficient were categorized into Matchers, Sorters, and Multiple-Choice

Table A1. Summary of the Literature Review

Research Theme	Literature	Research Topic	Theoretical Framework	Research Methods	Main Findings
					concepts.
	Park et al. (2019)	Developing a gamified system for information technology training	Theory of intrinsically motivating instruction	Design science	Participants using GAMESIT showed improved learning outcomes, including knowledge comprehension, task performance, and higher engagement compared to those using the non-gamified e-training system.
	Liu et al., (2017)	Developing a framework for design and research of gamified information systems	Task-technology fit theory	Conceptual design	A taxonomy of gamification design elements was presented. A framework for research and design was developed with the main theme of creating meaningful engagement for users. Gamified information systems should address both instrumental and experiential outcomes. Design principles and research questions were developed using a running case to illustrate ideas.
Evaluation of gamified learning	Santhanam et al. (2016)	Video-based training in database management course	Technology-mediated training (TML), Game-based learning	Experiment design	No one competitive structure can simultaneously address learning and engagement outcomes.
	Leung et al. (2023)	Online ICT course	Self-regulated learning (SRL), goal orientation, and gamification design principles	Longitudinal field experiment	Self-regulated learning (SRL) engagement and learning outcomes of participants who had a strong performance-avoidance goal orientation increased with positively framed performance feedback that involved no social comparisons; however, the same feedback had a negative impact on participants with a strong mastery goal orientation
	Cronan et al. (2012)	Objective vs. self-assessed perceptions of learning in an ERP business simulation game	IT knowledge	Field study (Survey)	Self-assessed measures yielded similar results to objective measures, indicating successful learning.
	Dominguez et al. (2013)	E-learning gamification system in online ICT course	motivational impact of different gamification mechanisms	Experiment design	While students who completed the gamified experience scored better in practical assignments and overall performance, they performed poorly on written assignments and participated less in class activities, despite initially showing higher motivation.
	Cheng et al. (2009)	Math competition games in classroom	Equal opportunity tactic design for competition	Experiment design	The equal opportunity approach could lessen the impact of individual differences in ability on perceived performance and beliefs about students' potential achievements. In simpler terms, students with less ability could have a similar chance of success and confidence as students with more ability in a competitive setting.

Table A1. Summary of the Literature Review

Research Theme	Literature	Research Topic	Theoretical Framework	Research Methods	Main Findings
	Hanus and Fox (2015)	Effects of gamification in communication course learning	Cognitive evaluation theory and social comparison theory	Longitudinal field study (survey)	A gamified system with special reward features had detrimental effects on students. It resulted in decreased motivation, empowerment, and satisfaction over time. Additionally, the gamified course diminished intrinsic motivation, leading to lower final exam grades.
	Burguillo (2010)	Competition games in telecommunication engineering course learning	Game theory, Competition-based Learning theory	Experiment design	Combining game theory with friendly competitions motivates students and improves performance.
	Ding et al. (2017)	Student engagement in gamified online discussions	Motivation theory	Mixed methods research (qualitative and survey)	Gamified online discussion tools have a positive influence on student behavioral engagement, emotional engagement, and cognitive engagement. Game elements such as badges, thumbs-ups, progress bars, and avatars in gamified online discussion tools promote student engagement in online discussions.
	Kyewski and Kramer (2018)	Impact of badges on motivation, activity, and performance in an online ICT course learning	Motivation theory and social comparison theory	Experimental field study	Badges have less impact on motivation and performance than commonly assumed. Students' intrinsic motivation decreased over time, regardless of the condition. Surprisingly, badges that only students could view were evaluated more positively than those viewable by others.
	Cheong et al. (2014)	Student perceptions of game elements in online learning	Game-based learning	Field study (Survey)	Students prefer social interaction, engagement, feedback, and increased learning, indicating that gamification is well-suited for learning styles like social constructivism.
	Hakulinen and Auvinen (2014)	Effect of gamification on students with different achievement goal orientations in online learning	Achievement goal orientation theory	Experiment design	The behavior of students with different goal orientations regarding badges showed no significant differences, but their attitudes varied. Students with high motivation toward badges exhibited higher mastery-intrinsic, mastery-extrinsic, and performance-approach orientation, and lower avoidance-orientation. All were high-performing before the badges were introduced, but not all high-performing students were motivated by the badges.
	Mekler et al. (2017)	Effects of individual gamification elements on intrinsic motivation and performance	Self-determination theory, Achievement goal theory, and Causality orientation theory	Experiment design	Game elements did not significantly affect competence or intrinsic motivation, irrespective of participants' causality orientation. However, points, levels, and leaderboards led to a significantly higher amount of tags generated compared to the control group, acting as extrinsic incentives for promoting performance quantity.
	Landers et al. (2017)	Impact of leaderboards on employees' image annotation task	Goal-setting theory	Experiment design	The presence of a leaderboard successfully motivated participants to improve their performance, and its impact was moderated by the individual goal commitment.

Table A1. Summary of the Literature Review

Research Theme	Literature	Research Topic	Theoretical Framework	Research Methods	Main Findings
		performance			
	van Roy and Zaman (2018)	Effects of need-supporting gamification on motivation in brainstorming task	Self-determination theory	Longitudinal field study (survey)	Need-supporting gamification can help counter the decline in students' motivation, but the effects may not be immediate. Personal characteristics may mediate the relationship between gamification and motivation.
	Zhou et al. (2020)	Feedback design and dispositional goal orientations on volunteer performance in citizen science projects	Achievement goal theory	Experiment design	Individuals' dispositional goal orientation significantly interacts with feedback design to affect volunteers' experiences. Additionally, volunteers' perceived enjoyment, meaning, and self-expansion positively influence their performance, measured by the quantity and accuracy of their contributions.
	de-Marcos et al. (2016)	Game-like and social approach gamification on learning performance in ICT course	Social gamification of learning	Experiment design	All experimental conditions, such as educational games, social networking, gamification, and social gamification, significantly impact learning performance. However, social gamification yielded better results in terms of immediacy and for all types of assessments.
	Krause et al. (2015)	Student retention in online education with social gamification	Peer assessment model	Experiment design	The gamification with social game element significantly amplifies the students' retention period and average test score.
	Tenório et al. (2016)	Developing a gamified peer assessment model in massive open online programming course	Gamification and social factors of learning	Experiment design	The use of gamification has increased the students' access to the system, the number of essays written and submitted, and the quantity and quality of assessments for each essay.
	Tsay et al. (2018)	Student learning experience with technology-mediated gamification in professional development course	Self-determination theory, Organismic integration theory	Field study	Student performance was significantly higher among those who participated in the gamified system than in those who engaged with the non-gamified traditional delivery. Behavioral engagement in online learning activities was positively related to course performance.
	Haug et al. (2014)	Effect of open badges and certificates of attendance on learners' motivation in massive open online ICT course	Self-determination theory, Cognitive evaluation theory	Case study	The engagement of MOOC participants decreases over time, making it challenging to motivate active learning. However, regular newsletter readership indicates its effectiveness in maintaining participant engagement. Additionally, pursuing open badges or certificates helps mitigate the decline in participant investment, supporting ongoing participation.

Appendix B: Construct Measurement Items

Table B1. Construct Measurement Items

Construct	**Measurement Items**
Game Design (Adopted and revised from Fu et al., 2009)	1) I received proper feedback from the lab game on my progress. 2) I received enough feedback on my actions in the lab game. 3) I was notified of new tasks/events in the lab game promptly. 4) I received information on my success (or failure) of goals in the lab game. 5) The lab game rules were presented in the beginning of the game. 6) The lab game rules were presented clearly.
Appropriate Challenge (Adopted and revised from Fu et al., 2009)	The difficulty of challenges decreased as my skills improved. The lab game provided appropriate challenges.
Competitiveness (Adopted and revised from Giannetto et al., 2013; Liu et al., 2013)	1) The lab game created a competitive environment. 2) I tried do my best to get better performance in the lab game than other students. 3) I spent significant amount of time playing this lab game to get a better score. 4) I enjoyed competing with others in the game.
Intrinsic Motivation (Adopted and revised from Ryan & Deci, 2000; Shernoff et al. 2003; Reeve, 2002)	1) I liked playing the lab game because it was challenging. (Excluded from the analysis) 2) I liked to learn as much as I can from the lab game. 3) I would like to go on to new lab game that is at a more difficult level. 4) I would like to continue my cyber security studies with more advanced lab-like games. 5) I like complex lab games because I enjoy trying to figure them out. 6) I like difficult lab games because I find it more interesting. 7) I asked questions about the lab game because I wanted to learn new things. 8) I made an extra effort in lab game because I can learn about things that interest me. 9) I played the lab game really hard because I really like to learn new things. 10) I liked to try to figure out how to do well in the lab game on my own. 11) When I didn't understand something in the lab game right away, I liked to try to figure it out by myself. 12) When I made a mistake in the lab game, I liked to figure out the right answer by myself. 13) If I got stuck in the lab game, I kept trying to figure out the problem on my own.
Extrinsic Motivation (Adopted and revised from Ryan & Deci, 2000; Guthrie & Wigfield, 2000)	1) I think that playing the lab game will help me better prepare for my job. (Excluded from the analysis) 2) Playing the lab game eventually will improve my job prospects. 3) Playing the lab game will help me find the type of job I am interested in. 4) I believe that playing the lab game will improve my competence as a worker. 5) I played the lab game to prove to myself that I am capable of completing this course successfully. 6) I played the lab game because of the fact that when I succeed in this course I will feel important. 7) I played the lab game to show myself that I am an intelligent person. 8) I played the lab game because I want to prove myself that I can succeed in this course.
Career Interest (Adopted and revised from Tobey et al., 2014, Cheung et al., 2012, Bashir et al., 2017)	1) I am interested in learning cybersecurity. 2) I feel confident in accomplishing the following labs. 3) I am considering cybersecurity as a possible career after graduation. 4) The gamified lab made me more likely to pursue a career in cybersecurity
Learning Outcome	1) Student's average score from the exam questions related to the topic covered in the gamified lab exercises

Appendix C: Interview Protocol

The interview protocol includes the following key elements:

Table C1. Interview Protocol

Introduction	Each interview commenced with a comprehensive introduction provided to participants. This introduction not only clarified the research's objectives but also emphasized the voluntary nature of their participation.
Consent	Following the introduction, participants were presented with a consent form that outlined their rights as participants. This included provisions for confidentiality and emphasized the voluntary nature of their involvement. Informed consent was obtained from each participant before proceeding with the interview.
Interview Questions	The interview questions were categorized into four main sections: General and Engagement: These questions aimed to gain insights into participants' general experiences and their levels of engagement with gamification labs. Mechanics Factors: This category delved into the technical aspects and mechanics involved in participants' interactions with gamification labs. Dynamics Factors: This category explored the dynamics, interactions, and relationships within the gamification lab context. Emotions Factors: Focusing on the emotional dimensions of their experiences, this category included questions that encouraged participants to reflect on their emotional responses.

Appendix D: Interview Findings

Table D1. The Themes Identified from Interview Responses and Quotes

Aggregated Themes	First-Order Themes, Reflection Notes	Quotes
Appropriate Challenge and Competitiveness: This theme explores how game design elements like leaderboards and instant feedback can motivate students while also providing appropriate levels of difficulty to foster critical thinking.	**Learning Process:** Participants appreciated the step-by-step guidance in gamified labs, indicating that clear instructions help in understanding complex tasks.	*“It provides step-by-step instructions on what you’re doing and why you’re doing it. So there’s more understanding and more knowledge being earned and learned at the same time.”* *“[In tasks with step-by-step instructions], you get to respond with a second chance.”* *"I think the lab helped you follow the steps sequentially, making it feel less difficult than it would have been on a PDF or document. Yeah, it didn't make me want to give up and walk away; instead, I wanted to keep going, earn my points, and finish the task."*
	Preference for Instant Feedback: Students preferred interactive labs over traditional ones, as they provided instant feedback on their scores and positions on the leaderboard.	*“It's like a real-time game, and you immediately see the changes [of points] after solving a task.”* *“I like the instant feedback... I thought it was very rewarding to get the notification and see the result that it worked.”* *“answering all the questions correctly is important, it was also very important to get the notification of the result that it worked.”*
	Competitive Motivation: Leaderboards motivated participants to excel, suggesting that competition can enhance engagement and effort.	*“It does because [the leaderboard] makes you want to be on top."* *"Once I realized it was more attainable if I just did my work, I was very motivated to be the best and get up there."* *"I feel like having that leaderboard makes everyone individually work harder."* *"I want to win the game because I'm a competitive person, and I really tried to be the first and the best."* *"When I looked at the scores of others, I thought, 'Yeah, I need to be on top.'"*
Students’ Experience and Accessibility: This theme focuses on how game design elements improve the ease of following instructions for better navigation, adapt to students’ diverse needs for visual aids, and enhance accessibility from different devices.	**Ease of Following Instructions:** Participants preferred instructions that were broken down into smaller web pages rather than a large document for easier navigation.	*“It's easy to navigate. It's easy to understand. It's very user-friendly.”* *“It's smaller pieces, so it's easier to take a pause,”* *“for example, when I had a 10 min break. I felt I was able to do maybe one task when waiting between classes.”* *"I think some of the harder tasks were really well broken down into smaller pieces, so you could move through them pretty well. "*
	Visual Learning Aids: Visual learners found the instructions and challenges with visual aids, such as instructional diagrams, demonstration screenshots, and images of challenges, to be helpful.	*“It was more eye-catching than just having a list of what to do, like in those command lines and stuff. Having those screenshots helped keep me engaged."* *“It made the labs feel less like homework and more like little puzzles to figure out."* *"Gametize for sure. Because it's more visually appealing, and the directions don't look all clumped together on the page. On documents, everything just looks clumped together, and it's just not appealing."*

	Learning Style Considerations: The preference for visual and gamified elements highlights the need to accommodate diverse learning styles.	*"I'm a visual learner, so having a lot of screenshots in the material was really helpful."* *"I found the gamified labs to be a lot more interesting and much easier to understand."*
	Preference for Accessible Materials: Participants appreciated the web-based platform's ability to provide easy access from different devices.	*"I was able to access it on my phone or my iPad."* *"It's available anytime, so you can do it at your own pace."*
Enhanced Motivation: This theme examines how clear instructions, visual aids, and gamification strategies can motivate students and support their learning efforts.	**Alignment of tasks with contextual mission descriptions and instructions:** Gamified labs were found more enjoyable and engaging when the tasks were aligned with contextual mission descriptions.	*"It makes me feel more real in the sense that I could use this one day, I feel like it really draws attention and like the desire to learn it because it forces you to learn to solve a problem."*
	Enjoyment and Learning: Participants enjoyed the gamified labs, which suggests that enjoyment can enhance the learning experience.	*"The gamified labs were a lot more interesting and easier to understand,"* *"I had that satisfying feeling at the moment of earning the points."* *"I really liked being hands-on throughout all the labs, and the gamified ones were more fun as well, so I liked having them."* *"I think it's fun to compete with your classmates and see who actually puts in the effort to finish quickly and well. Also, if you're stuck, you can always go and ask for help from those people, which is nice."* *"I think it had a positive effect because it made the class more enjoyable."*
	Interplay of Intrinsic and Extrinsic Motivations: Participants' feedback revealed a dynamic interplay of intrinsic and extrinsic motivators within gamified learning settings.	*"it was very enjoyable … and I always put the storyline at the top three because it's feel storylines is really good for students to follow"* *"understanding the material and getting like real world examples,..., showing us what we're learning and how it can be applied."* *"It does because [the leaderboard] makes you want to be on top."*
Students' Learning and Career Interests: This theme explores how educational tools and strategies can align with students' career goals and personal interests,	**Practical Application of Knowledge:** Gamified labs provided practical real-world examples, enhancing the relevance and application of theoretical concepts.	*"understanding the material and getting like real world examples,..., showing us what we're learning and how it can be applied."* *"it was very enjoyable … and I always put the storyline at the top three because it's feel storylines is really good for students to follow".I feel like using the Gametize game and engaging in hands-on exercises instead of a worksheet led to more learning and practice."* *"It provided a more tangible example of what that looks like in the real world."*

enhancing the relevance and practical application of their learning experiences.	**Critical Thinking in Gamified Labs:** Some participants felt gamified labs encouraged critical thinking, highlighting the value of interactive challenges.	*"understanding the material and getting like real world examples,..., showing us like what we're learning and how it can be applied."* *"For me, learning by doing is very interesting. You learn something new while doing labs."* *"Understanding why is important… it was easy once you grasp the overall concept of what you're doing,"* *"I also really liked that we weren't using a textbook during class and just doing worksheets; instead, we were actually solving something and thinking about it."* *"And if there's something I do not understand from the game, I will try to Google it to find answers or related subjects."*
	Independence in Learning: Gamification encouraged independent learning, as students sought out additional resources to improve their scores.	*"It adds a level of self-motivation and makes you want to be the best and earn that spot. So having that there makes you more independent"* *"There were a couple of tasks where I had to go back to Google and check some things"*

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